Assessment of body motions using Motion Energy Analysis – Instructions for MATLAB© scripts. Version 2.0

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Version 2

About this version: Compared to the previous version, the working procedure of the motion energy analysis is unchanged. However, now the scripts were adapted to handle various video formats. On that reason a (time consuming) conversion of a video is no longer necessary. Furthermore, we implemented graphical user interfaces for easier handling and extended the description of scripts.

In January 2019, we deleted a bug in the script `MEA_and_preprocessing_of_a_directory.m` and added optional parameters for this script. The changes are related to usability and have no impact on the resulting motion energy time series.

1 Background of Motion Energy Analysis

Motion Energy Analysis (MEA) is a computerized method to automatically assess body motions of videotaped individuals. This computer vision method has been applied to assess body movements in many research areas. For example, correlations between body motions and severity of negative symptoms in patients with schizophrenia (Kupper, Ramseyer, Hoffmann, Kalbermatten, & Tschacher, 2010; Kupper, Ramseyer, Hoffmann, & Tschacher, 2015) or between politicians' movement patterns and their personalities (Koppensteiner & Grammer, 2010) have been reported. Furthermore, synchronisation of body motions assessed with MEA has been examined in positive versus negative situations in children interactions (Altmann, 2010, 2011, 2013) and adult interactions (Paxton & Dale, 2012). MEA has also been applied to analyse the nonverbal behaviour in a psychotherapeutic context via studying the synchronisation of motions in patient-psychotherapist interactions (Altmann, Schoenherr, Paulick, et al., 2018; Galbusera, Finn, & Fuchs, 2016; Paulick et al., 2017; Paulick et al., 2018; Ramseyer, 2011; Ramseyer & Tschacher, 2011, 2014; Schoenherr, Paulick, Strauss, et al., 2018; Schoenherr, Paulick, Worrack, et al., 2018). Furthermore, the synchronisation of voice and body motion in mother-new born baby interactions (Watanabe, 1983), teacher-learning group interactions (Katsumata, Ogawa, & Komori, 2009), and in courtship communication (Grammer, Honda, Juette, & Schmitt, 1999) have been examined using motion energy time series (METS). Moreover, MEA is commonly used in human-machine interactions, whereby robots use MEA to perceive human motions, gestures etc. (Bobick, 1997; Boehme et al., 1998).

Starting from the point that movements of two persons are recorded using a digital video, the attached MATLAB© scripts assess their body motions. A detailed explanation of MEA is given by Altmann (2013) (in German) and Altmann, Schoenherr, Dittmann, et al. (2018) (in English). The attached MATLAB© scripts regarding MEA were written and developed by Uwe Altmann. In an ongoing project of the Institute of Psychosocial Medicine and Psychotherapy (Jena, Germany), the scripts were extended by Désirée Schoenherr (née Thielemann) so that the scripts works with various videos formats, the regions of interests can be defined with a free-hand tool (e.g., to examine only head movements) and video errors can be filtered.

2 Requirements

To apply the scripts respectively MEA on your video, the following is required:

1. When recording the video you should take care that the person is completely visible, the preferred view should be the front view or the side view. Light conditions should be optimal (i.e., no light reflections of window). Videos should be excluded, if a person covers the other person in the video frame. If the examined persons sit while recording, it should be ensured that this position is keep during the entire video (no standing up). Good recording settings (including pictures of the setting) are described by Altmann (2013), Ramseyer and Tschacher (2011) or Tschacher, Rees, and Ramseyer (2014).
2. Video format: If you examine a sample of videos, make sure that all video files have the same format. In our studies we preferred `avi` files. Possibly, it is necessary to cut the video (e.g. cut out the starting sequence when both persons sit down, or the ending sequence when both persons stands up and leave the recoding room).

3. MATLAB: We tested all scripts with MATLAB R2016 for Windows. The error-free operation using a previous version of MATLAB or another operating system cannot be guaranteed.
4. One digital **colour** video: As input, the scripts expected a digital video. In our studies, we used AVI files with 25 frames per second (fps), frame size of 640x480 pixel, and a bitrate of 2000 Kbits/second. Please note, that the scripts can handle other formats, for example, a video size of 1280x1024. The video formats which are supported by MATLAB are listed in the description of MATLAB (e.g., in the context of the command `VideoReader`). Please note, that we did not check the error-free operation of all possible video formats and sizes.
5. **Important**: All scripts of this package should be downloaded and saved in a separate directory, e.g. a sub-folder in your home directory. This directory **must** be included into the MATLAB list of search paths. To do that use the command `PATH` or the menu point "home", then "set path", then add the directory to the list. If this does not work (e.g. because admin rights needed), you can save the file in the so called MATLAB directory (e.g. `C:\Users\user01\Documents\MATLAB`).

3 Instructions for Motion Energy Analysis (MEA)

3.1 Steps of MEA: Overview

In the first step, you must define the region of interest (ROI; script `MEA_ROI_freehand_v04.m`). With the script, two interacting persons can be examined. For these two persons, four different regions of interest were recorded: body of the first person, body of the second person, head of the first person, and head of the second person. This was the typical setting in our studies referring to patient-therapist interactions. The second step is an optional data driven estimation of a threshold which is used later to filter noise (script `estimate_threshold_for_MEA.m`). In the third step, the motion energy analysis is applied using the defined ROI (script `MEA_2persons_body_head.m`) and the noise filter threshold. In the fourth step, various pre-processing methods can be applied on the resulting motion energy time series. We recommend a standardization of the value range of the time series using the size of ROI (script `standardize_ROIsize.m`). Furthermore, we provided a script for an additional threshold based filter of video errors (script `filter_video_errors_in_TS.m`) and a simple data-driven filter of video errors namely a moving median (script `moving_median.m`). In the following, all named script will be described in detail.

3.2 Step 1: Definition of ROI

The MEA measures changes of colour intensity of pixels over time. In other words, MEA is a frame-differencing technique, where pixels that change their colour intensity from one frame to the next are counted. The algorithm is not able to identify body parts. Furthermore, it cannot track objects in the video. Important pre-conditions are: (1) the camera position is fixed, (2) there is no zooming (therefore, automatic zoom options should be disabled using modern hand cameras) (3) the background does not change, (4) the recorded persons must be visible (avoid for example white clothes with white background), (5) a person covers the other in the video frame, and (6) the movements of a person must be restricted to a region in the video frame. In our studies, two people sitting facing each other.

In the first step of motion energy analysis, you must define regions in the video frame where the concerning movements of both persons takes place. An optional input parameter of the script `MEA_ROI_freehand_v04.m` is the name of video file (including the directory), for example:

```
MEA_ROI_freehand_v04('C:\temp\my_video.avi')
```

If a video file is not specified, for example by using the following command line

```
MEA_ROI_freehand_v04
```

the script opens a graphical user interface which allows the selection of video file per hand.

In the next step, the four regions of interest (ROI) must be drawn by the user: body of patient, body of therapist, head of patient, and head of therapist. Figure 1 shows an example. Please note that the numbering of ROI in Figure 1 corresponds to the numbering within the script. The scripts open a graphical user interface which show one of the first video frames. As default frame the script displays the frame at minute 2 (frame number 3000). A ROI can simple drawn by hand using the mouse cursor. Please consider the output in the command window. The script states which of the four ROI mentioned above is currently recorded.

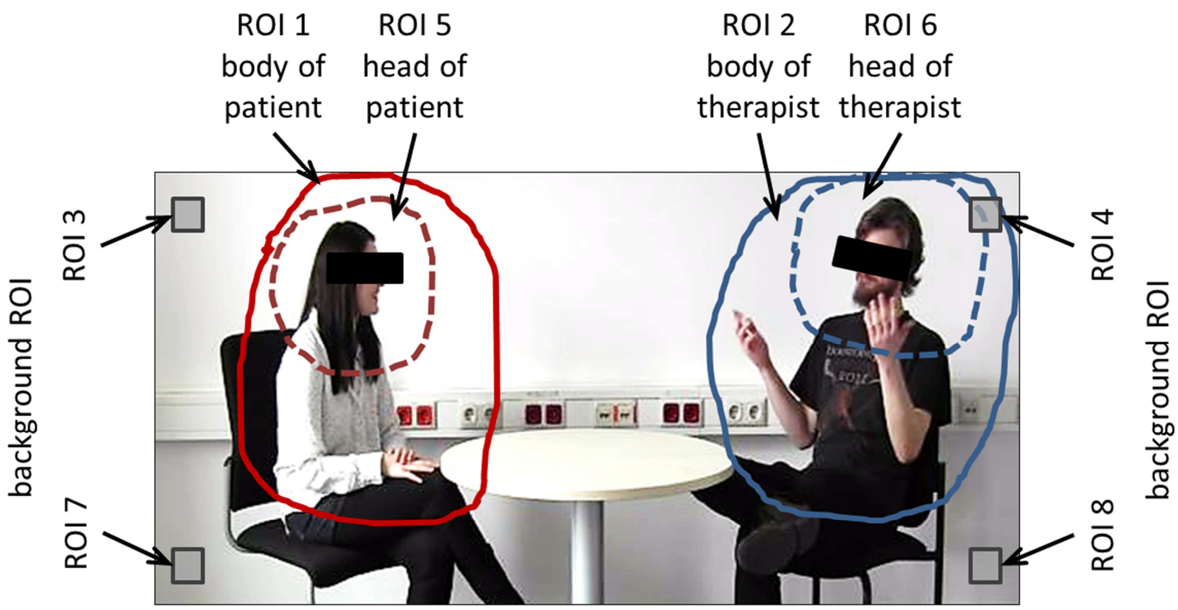

Figure 1: Regions of interest in a video frame.

Note, that the script defines automatically four background ROI (in Figure 1: ROI 3, 4, 7, and 8). These ROI are relevant to filter noise. Idea and procedure are described in detail by Altmann (2013). It is assumed that in the background no colour changes should occur. The motion energy of a background ROI should be zero at each time point. Colour changes in the background ROI indicate fluctuations of light or other disturbances of the video signal. If those are detected, the motion energy values of body and head ROI were set to missing value automatically. Furthermore, we recommended to inspect the corresponding time points in the video.

It is possible that body ROI and background ROI overlap. In Figure 1, this holds for ROI 2 (body of therapist) and ROI 4 (background ROI in the upper right corner).The script proofs such constellations automatically and select two background ROI (ROI 3 and 4 versus ROI 7 and 8). Thus, either the both upper background ROIs or the both lower background ROIs are used. The default are the upper background ROIs. If one is interested in which background ROIs are used, one may use the `size_rois` variable, which is stored in the resulting `*_rois.mat` file. If the variable contains a zero as last number, upper background ROIs were used; if it contains a 1, lower background ROIs were used. If one of the upper background ROI (ROI 3 and 4) and one of the lower background ROI (ROI 7 and 8) overlap with the body or head ROI, then the script ends with an error message.

The script saves a `*_rois.mat` file which consisted the ROI for body of patient, body of therapist, head of patient, and head of therapist as well as two background ROI. Furthermore, the file included a vector with the size of each ROI which later used to standardize the range of motion energy values. The `*_rois.mat` file have the name of selected video (e.g. ROI file name "`my_video_rois.mat`" corresponds to the video file name "`my_video.avi`") and is saved in the same directory as the video file. The `*.mat` file can be opened with MATLAB.

3.3 Step 2 (optional): Estimation of threshold for filtering noise

As you know, MEA counts the pixel in a video frame (more precisely in a ROI) whose colour value changed substantially from t to t+1. Sometimes video errors can occur (e.g., light reflections by a window, or other noise especially if you use very old videos in VHS format) so that changes of the colour intensity are caused by noise and not by body movements. These video errors bias the subsequent analysis of motion energy time series (e.g., computation of movement speed or movement synchronization of two interaction partners). However, these video errors can be partially filtered by an application of a threshold. This threshold quantifies which colour intensity change of a pixel from t to t+1 is needed to count the pixel as "movement". The default value is 12. The colour video is converted automatically into a black and white video with 256 gray scales. A threshold of 12 means that the difference of gray intensity of frame at t and gray intensity of frame at t+1 must be larger than 12. Otherwise, the change of gray intensity is interpreted as noise (and is filtered in the later MEA). This method of threshold estimation was applied in studies using (very noisy) VHS videos, e.g. by Altmann (2013).

Before you run the script `estimate_threshold_for_MEA.m`, it is necessary to define the ROI (`MEA_ROI_freehand_v04.m`) because the script need to know where are the background ROI are located. The command line is:

```
[cut_off99, cut_off95] = estimate_threshold_for_MEA(videoName)
```

The input parameter `videoName` is a string which defines the name of video file including the directory (e.g., `videoname = 'C:\temp\my_video.avi'`). The output parameters are integers. The first is the 99% quantile of all difference values of background ROI pixel. We recommend this value. The second is the 99% quantile (and not so conservative).

Please note that the script displays the estimated threshold, too. Moreover, if no video file name was specified the script opens a graphical user interface so that the video file can selected manually. Therefore, you can also run the script on this way:

```
estimate_threshold_for_MEA
```

The script loads the video and the corresponding `*.mat` file which was generated by the script `MEA_ROI_freehand_v04.m`. Difference frames are computed for both background ROI. In a video with good quality the colour intensity in the background should not change respectively the difference values of background ROI pixel from *t* to *t*+1 should be zero. As result, the script provides two time series storing each pixel change with respect to the two background ROI. Then, all time series were concatenated and the values were sorted by size. Altmann, Schoenherr, Paulick, et al. (2018) and Schoenherr, Paulick, Strauss, et al. (2018) used the 99% quantile as threshold.

Please note that a high threshold can be caused by noise but also by a sub-optimal position of the background ROI, for example, if the ROI is placed on a window and movements of clouds or trees are recorded. It is not necessary to apply the script `estimate_threshold_for_MEA.m` on each video of a study. If the videos are recorded in the same laboratory and have approximately the same quality, then it should be enough to check ten videos. The threshold should be equal in each video. If there are differences, take the most conservative value. A very conservative value for digital videos is 12.

3.4 Step 3: MEA

The script `MEA_2persons_body_head.m` analyses the video. Before you run this script, you must define the ROI using the script `MEA_ROI_freehand_v04.m`. Two (optional) input parameters can be specified. The command line is:

```
MEA_2persons_body_head(videoNames, cut_off)
```

The input parameter `videoNames` is a string with the directory and name of video file (e.g., `‘C:\temp\my_video.avi’`). The parameter `cut_off` specifies the threshold for meaningful pixel change intensity. The default value is 12. You can estimate this threshold using the script `estimate_threshold_for_MEA.m` (see step 2, above).

You can also run the script without specification of any parameters. The corresponding command line is:

```
MEA_2persons_body_head
```

In this case, the script uses the default value (`cut_off = 12`) and opens a graphical user interface for the selection of video file.

After parameter specification, the script loads the information about regions of interest saved in in the file `*.mat` file (see step 1; output of the script `MEA_ROI_freehand_v04.m`). Then the script proceed a MEA for the six

ROI which are specified in the file `*.mat` file. The output of the script is a `.txt` file containing the motion energy values for the video sequence in 6 columns: (1) patient body, (2) therapist body, (3) background ROI left side, (4) background ROI right side, (5) patient' head, and (6) therapist' head. The line corresponds to the measurement time point *t*. Line 23 in the `.txt` file refers, for example, to video frame 23. The values of a column can vary between zero and the size of corresponding ROI (see step 1).

Please note that the script saves the results in a tab-spaced `*.txt`. The file name includes the video file name and the abbreviation "MEA" and information about the applied threshold respectively cut off value, for example "`co12`" means that the cut off value was 12. The file is saved in the directory of video file.

3.5 Step 4: Pre-processing

The application of pre-processing methods on motion energy time series is optional, but highly recommended. Figure 2 shows an example. In the 1st line a motion energy time series is plotted (the "raw data" after MEA). The 2nd line shows the same time series after standardization with the size of ROI (with script `standardize_ROIsize.m`). The only difference is the scaling of y-axis. In the 3rd line, video errors at the beginning of video are filtered (with script `filter_video_errors.m`). In the 4th line, the time series is additionally smoothed with a moving median (using the script `moving_median.m`). In the following, the scripts are described in detail.

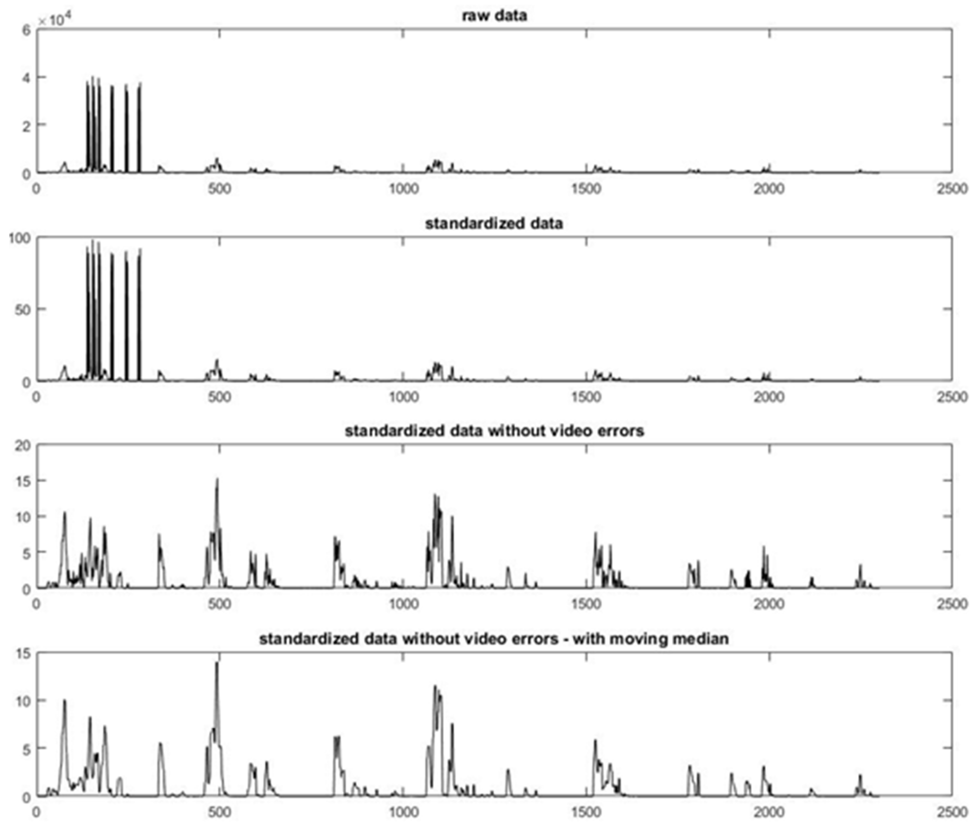

Figure 2: Impact of pre-processing steps on a time series.

3.5.1 Step 4a: Standardization of value range of motion energy time series

First, the value range of motion energy time series should be standardized using the size of ROI (script `standardize_ROIsize.m`). The corresponding command line is:

```
standardize_ROIsize(time_series_file_name, ROI_file_name)
```

The parameter `time_series_file_name` is the output file of the script `MEA_2persons_body_head.m`. The parameter must contain the directory and file name (e.g. `'C:\temp\my_video_MEA_co12.txt'`). The corresponding file must contain the time series which should be standardized. The parameter `ROI_file_name` is the directory and name of `*.mat` file which includes the ROI for the body of patient, body of therapist, head of patient, and head of therapist as well as two background ROI (e.g. `'C:\temp\my_video.mat`).

You can also run the script without specification of any parameters. The corresponding command line is:

```
standardize_ROIsize
```

In this case the script opens graphical user interfaces for the selection of both files.

The equation behind the standardization is $Y = X \cdot 100/S$ whereby S is the size of ROI, X the motion energy time series referring to this ROI and Y the new time series. Due to the standardization the value range of new time series varies between zero (no “activity” at this time point) and 100 (the entire ROI is activated). The standardization is applied on each time series referring to body movements, head movements and background ROI.

The output of the script is a `*.txt` file. The structure is equal to the output of the script `MEA_2persons_body_head.m` (see above). The columns are: (1) patient body, (2) therapist body, (3) background ROI left side, (4) background ROI right side, (5) patient’ head, and (6) therapist’ head. The line corresponds to the measurement time point (resp. video frame). The file name is the name of the `*.txt` file (output of the script `MEA_2persons_body_head.m`) plus “stand” (for standardization).

3.5.2 Step 4b: Additional filter of video errors

We provided a script for an additional threshold based filter of video errors (script `filter_video_errors.m`). Schoenherr, Paulick, Strauss, et al. (2018) inspected standardized motion energy time series of video sequences with videos errors (e.g., light reflections of a window).

In a visual inspection of hundreds videos, Schoenherr, Paulick, Strauss, et al. (2018) found that video errors (e.g., light reflections of a window) are correlated with increase of standardized motion energy about 15% and a decreases about 15% within three frames (respective 25% for head movements). The script detects such rapid changes and sets the corresponding motion energy values to missing values. Furthermore, the script assumes a video error, when the standardized motion energy of a background ROI is larger than 5%. Then, the missing values were linear interpolated (given that the number of subsequent missing data values is smaller than 8 respectively 8 / 25fps = 0.32sec). Please note that the script `filter_video_errors.m` works only correct, if the time series is standardized with the script `standardize_ROIsize.m`. The command line for this script is

```
filter_video_errors( TXT_file_name, cut_off_body, cut_off_head,
cut_off_background)
```

The input parameter `TXT_file_name` is the `*.txt` file with the motion energy time series – more precisely the output of `MEA_2persons_body_head.m` standardized with the script `standardize_ROIsize.m`. (e.g. `'C:\temp\my_video_MEA_co12_stand.txt'`). Optional parameters are the threshold for background ROI (`cut_off_background` ; default is 5), the threshold for body motions (`cut_off_body`; default is 15), and the threshold for head motions (`cut_off_head`; default is 25).

We recommend the default parameter. If no `*.txt` file is specified, the script starts a graphical user interface for the manual selection of `*.txt` file. The command line is:

```
filter_video_errors
```

The output of the script is a tab-spaced `*.txt` file. The columns correspond to the input file: (1) patient body, (2) therapist body, (3) background ROI left side, (4) background ROI right side, (5) patient' head, and (6) therapist' head) whereby values which were caused by the video errors are filtered and replaced with interpolated values. The name of output file is the name of input plus the abbreviation "`vef`" (video errors filtered).

3.5.3 Step 4c: Smoothing with moving median

Furthermore, we implemented a data-driven filter of video errors namely a moving median. The command line is

```
moving_median_for_txt_file(TXT_file_name, bandwidth )
```

Input parameters are a tab-spaced `*.txt` file (output of the script `filter_video_errors`) and the integer value `bandwidth`. The script applies a moving median on each time series (column of file) and save the results in a new tab-spaced `*.txt` file. The output file name is the input file name plus the abbreviation "`mm`" (moving median).

3.5.4 Step 4d: Logarithmic transformation

With the command line

```
log_transformation_for_txt_file( TXT_file_name )
```

a logarithmic transformation is applied on the time series in the tab-spaced file `TXT_file_name` (e.g. the output of the script `moving_median_for_txt_file.m`). The script save the transformed time series in a tab-spaced `*.txt` file. The name of output file is the name of input plus the abbreviation "`lf`" (logarithmic transformation).

4 Automation of MEA and pre-processing (step 3 to 4d)

4.1 One video

There are multiple steps to extract motion energy time series and to prepare these time series for a further analysis (e.g. regarding synchronisation of patient and therapist body movements). As mentioned above each script provides default values which applied in the study of Altmann, Schoenherr, Paulick, et al. (2018), Schoenherr, Paulick, Worrack, et al. (2018) and Schoenherr, Paulick, Strauss, et al. (2018). Before this background we implemented a script (`MEA_and_preprocessing_of_a_video.m`) which apply motion energy analysis (step 3) and all pre-processing steps describe above (step 4a to 4d) on a given video file. The command line is

```
MEA_and_preprocessing_of_a_video(video_file_name, cut_off)
```

If no video file is specified, the script opens a graphical user interface so that a file can selected manually. If no cut off value is specified, the default value (12) is applied. The cut off value refers to step 2 (see section 3.3).

It is important that the regions of interest were specified (step 1; script `MEA_ROI_freehand_v04.m`) before this script is started. If no `*.mat` file with ROI information is found, then the script ends without MEA.

4.2 All videos in a directory

A further automation is the script

```
MEA_and_preprocessing_of_a_directory(directory_name , video_format,
cut_off)
```

This script creates a list of all video files in the directory `directory_name`. If the parameter `directory_name` is not specified, the script opens a graphical user interface so that the directory can selected manually. If video files in the directory were found, then the script applies MEA and all pre-processing steps (step 3 and 4a to 4d) on each video using the default values. Please note that for each video file the regions of interest must be specified (step 1; script `MEA_ROI_freehand_v04.m`) before this script is started. If no `*.mat` file with ROI information is found, then the script skip to the next file in the list of video files.

Two further optional parameters are `video_format` and `cut_off`. The former is a string and defines the video format. The default value is `’avi’`. In case of non-specification, the default value is used. The latter refers to the cut off value of MEA (see step 2, section 3.3).

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